

Adoption of improved maize seeds and Sustainable Agricultural Intensification among rural households in Cameroon

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Keywords

*Cameroon, improved seeds, maize, rural
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Intensification*

ABSTRACT

In Cameroon, the sustainable intensification of agricultural production is essential to addressing environmental, economic and social challenges, particularly in rural areas where natural resources are under significant pressure and agricultural yields are low. Improved seeds clearly contribute to enhancing agriculture by requiring fewer inputs and promoting sustainability. Households that adopt these seeds benefit from increased yields and reduced crop losses, transforming subsistence farming in a sustainable way. This study analyses the impact of improved seeds on the sustainable intensification of maize production, which is the main crop for intensification among rural households in Cameroon, using data from the 2017 Cameroon Comprehensive Food Security and Vulnerability Analysis. Descriptive statistics, propensity score matching (PSM) and stochastic frontier analysis (SFA) indicate that 60.35% of the 4,101 households practise intensive maize cultivation, while 39.65% do not. Among those growing maize, 30.1% use improved seeds, yielding 344.45 kg/ha compared to 291.675 kg/ha for non-improved seeds. Adopting improved seeds thus increases the probability of achieving efficient and sustainable production by 21.8%. Technical, allocative and economic efficiencies are 0.52, 0.815 and 0.709, respectively. This suggests that, despite the risks of inefficiency associated with the overuse of fertilisers, pesticides and labour, improved seeds can increase yields and reduce input waste. Therefore, it is essential that public policy priorities focus on encouraging the adoption of improved seeds, providing market support, and creating sustainable seed systems.

INTRODUCTION

Processes of agricultural intensification, which began in Cameroon as part of government programmes in the 1970s, are now integrated into agricultural development strategies such as the National Rural Development Strategy and the National Sustainable Development Strategy (SDSR/PIA, 2020). These strategies acknowledge the significant potential of rural areas for increasing agricultural production, particularly maize production. This crop has been cultivated extensively in Cameroon in recent years due to the availability of arable land and the potential for irrigation (Guibert et al., 2016; SDSR/PIA, 2020; World Bank, 2020). The country has approximately 7.2 million hectares of land, but only 1.8 million hectares are currently cultivated. The potential for irrigation is estimated at 240,000 hectares (World Bank, 2020). Cameroon produces an average of 2.36 million tonnes of maize per year, with nearly 2.75 million rural households depending on this crop for their income. These households are seeking to increase their production. Furthermore, the diversity of agroecological zones makes intensive maize cultivation favourable, and rural households have a strong incentive to do so. This practice offers a vital way to boost their earnings, guarantee their food security and ease the strain on land (Guibert et al., 2016).

Although maize production in Cameroon has increased by around 4.4% per year, supply remains insufficient to meet the rapidly growing

domestic demand of over 2.8 million tonnes (SDSR/PIA, 2020; NIS, 2025). While it would be possible to increase the area under cultivation, this would seriously harm local communities and exacerbate the socio-environmental damage already evident in rural areas. This damage is primarily caused by erratic rainfall and prolonged periods of drought resulting from climate change, as well as the loss of soil fertility (WFP, 2017; World Bank, 2020). Indeed, infertile soils currently account for 25–30% of land suitable for maize cultivation in Cameroon, resulting in significantly lower yields. Furthermore, pressure on natural resources could increase considerably due to population growth and high demand for maize for consumption. This would exacerbate the economic and social vulnerabilities of rural populations who depend on this crop (World Bank, 2020).

Since 1990, the traditional approach of intensifying arable land has given way to seed programmes that aim to increase maize yields per unit area by ensuring seed security (Ball, 2016). Since then, public policies in Cameroon have encouraged the adoption of improved seeds in order to meet the growing demands of sustainable agriculture (De La Paix Bayiha et al., 2020). These state-managed programmes have increased maize yields by 10–30% since 2005, thereby promoting the intensification of this crop (MINADER, 2020). However, the adoption of improved maize seeds presents challenges in some rural areas due to inefficient supply chains, which constitute a significant barrier to intensifying this crop among rural households (Djamen,

2016; Ball, 2016; Takam-Fongang et al., 2019). According to the World Bank (2020), rural households in Cameroon face numerous obstacles preventing them from increasing production, food security and income, particularly due to limited access to improved seeds. In addition to this, sustainable agricultural intensification requires greater financial investment, a readily available labour force and improved knowledge and skills regarding seeds.

There are also concerns regarding the predominant maize farming systems in rural areas of Cameroon. These systems rely heavily on limited natural resources and demonstrate a low rate of improved seed adoption (Meughoyi, 2018; Takam-Fongang et al., 2019). This is leading to slower growth in agricultural yields, the resurgence of environmental problems and constraints on land and water that are hindering the long-term intensification of maize cultivation. Furthermore, rural development initiatives often overlook resource sustainability and improved agricultural practices, and access to improved seeds remains a major obstacle. However, the long-term intensification of maize cultivation in Cameroon depends on adopting inputs such as improved seeds, fertilisers, and modern techniques, which can increase yields beyond those achieved through traditional farming methods (Guibert et al., 2016). Consequently, in rural areas where access to improved seeds is limited, further intensification yields diminishing marginal returns that are often below the potential yields for maize (Ball, 2016).

These findings therefore prompt this study to examine the role of improved seeds in the sustainable intensification of agriculture among rural households in Cameroon. Using maize cultivation as a case study, the study will assess the economic, social and environmental effectiveness of this approach. With this in mind, the study formulates the following analytical hypothesis: improving the conditions for adopting improved maize seeds in Cameroon would enable rural households to produce goods efficiently and sustainably. This would make them more technically proficient in terms of agricultural intensification than their counterparts.

This study examines this relationship in five sections. It highlights the relevant conceptual and theoretical links and reviews the empirical research on sustainable agricultural intensification in Cameroon. It describes the methodology adopted, then presents and analyses the results obtained. Finally, the study concludes with an analysis of the implications for economic policy.

LITERATURE REVIEW

The concept of Sustainable Agricultural Intensification

Pretty et al. (2011) popularised the concept of “Sustainable Agricultural Intensification” to describe the goal of boosting agricultural production while safeguarding the environment and rural economies. This generally involves making the most of natural, social, and human capital while using the best available technologies and inputs to minimise or eliminate environmental damage. Similarly, Wezel et al. (2015) define sustainable agricultural intensification as increasing production from the same area of land while conserving resources, reducing negative environmental impacts, and enhancing natural capital and the flow of ecosystem services. In summary, sustainable agricultural intensification practices aim to improve the productivity and resilience of agricultural production systems while conserving natural resources. These practices involve adopting certain inputs and integrating multiple technologies, which together constitute a broader concept of sustainable intensification (Vanlauwe et al., 2014; Kassie et al., 2015).

Wezel et al. (2015) identified three main approaches to sustainable agricultural intensification: Socio-economic intensification promotes the development of innovative and sustainable institutions within farms, communities, markets, and rural areas. Ecological intensification is exemplified by agricultural practices that enhance the mutual benefits between crops, such as integrated pest management, conservation agriculture, and organic farming. Genetic intensification involves preserving beneficial genes and combining them with other complementary genes from close or distant relatives to improve the yield of cultivated varieties. The latter approach involves adopting improved seeds that are more productive, disease-resistant and suited to local conditions.

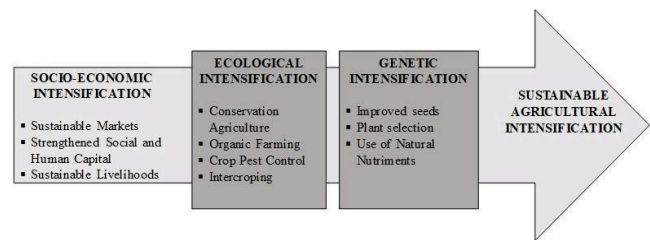


Figure 1. Approaches to Sustainable Agricultural Intensification.

Figure 1 shows the two main approaches to achieving Sustainable Agricultural Intensification: ecological intensification, based on ecological agricultural processes, and genetic intensification, which relies on modern plant breeding and improved seeds. Adopting improved seeds helps achieve the objective of sustainability by making farming more productive with fewer inputs (Louwaars & de Boef, 2012; McGuire & Sperling, 2016). Rural households experience the benefits almost immediately, as increased yields and reduced crop losses transform agriculture, moving it from a subsistence to a developmental phase. Improved seeds can also help agriculture adapt to constantly evolving climate threats and stresses, thus meeting environmental requirements (Sharrock, 2016).

Theoretical interpretation of the role of improved seeds in Sustainable Agricultural Intensification

The theoretical literature on the role of improved seeds in Sustainable Agricultural Intensification tends to focus on three areas: (i) their impact on productivity, (ii) their impact on natural resource management and (iii) their impact on the institutional framework of rural households (Pretty et al., 2011; Tittonell, 2014). All of these approaches are theoretically rooted in economic principles, the natural sciences and agroecology. However, these fields are fundamentally different: economists focus on economic changes, while agroecologists are concerned with environmental consequences and the long-term relationship between households and their environment.

From an economic perspective, the role of improved seeds in sustainable agricultural intensification is part of a broader theoretical debate about the need to increase agricultural production to meet the growing needs of rural populations (Turner & Wiber, 2009). Pingali et al. (1987) demonstrated that modest agricultural growth could sustain steady population growth if farmers adopted technical innovations. Consequently, in areas subject to high agricultural pressure, where production resources are dwindling — as is generally the case in rural areas — a more intensive approach to agricultural practices is required. This involves utilising intensification factors, such as improved seeds, to increase crop rotation and boost the amount of labour and technological resources devoted to intensifying agricultural production (Turner & Wiber, 2009).

For its part, ecological intensification aims to increase the yield potential of major crops and reduce yield variability by using precision

farming techniques based on scientific advances in agricultural science (Petersen & Snapp, 2015). It is therefore considered a way of increasing agricultural production while reducing dependence on external resources by utilising the ecological processes that sustain and regulate the primary productivity of agricultural ecosystems (Titttonell, 2014). The growing interest in improved seeds appears to be a response to the negative environmental and social impacts associated with intensive production strategies (Pretty et al., 2011; Garnett et al., 2013; Sharrock, 2016).

Adoption of improved maize seeds and intensification of maize production in Cameroon

Empirical literature (Ntsama & Kamgnia, 2008; Mabah Tene et al., 2013; Meughoyi, 2018; Takam-Fongang et al., 2019) clearly shows that rural households in Cameroon's adoption of improved maize seeds is influenced by various factors. These include the age and level of education of the household head, household size, experience, farm size, market access, the farmer's perception of high-quality maize seed characteristics, yield and profitability, membership of a farmers' association, attitude towards risk and access to credit.

Mabah Tene et al. (2013) attribute the low uptake of improved maize seeds in Cameroon to a mismatch between the supply of seeds and production prospects, and farmers' actual needs. This mismatch can be explained by several key factors: limited access to extension services; low levels of education in certain rural areas; a lack of adaptation to the local context; socio-economic constraints linked to the cost of inputs; labour constraints; and market risks. These factors do not always correspond to farmers' investment capacity and actual needs. Ntsama and Kamgnia (2008) explain that adopting improved maize seeds often requires additional investment, and that farmers with limited financial resources are negatively affected by difficulties in accessing credit when trying to adopt these seeds. Conversely, cooperative or farmers' organisation membership greatly facilitates access to finance and credit for seeds.

Both Andrianarison et al. (2021) and Mveng et al. (2023) have demonstrated that the age of the household head, level of education, size of the family labour force, area under cultivation, contact with extension workers, membership of a farmers' organisation, household income, and availability of improved seeds significantly influence their adoption. The main barriers to adopting improved seeds are high prices, insufficient resources, a lack of information, distance from markets and seed unavailability.

In terms of sustainable agricultural intensification, the adoption of improved seeds can be used as an example (De La Paix Bayiha et al., 2020). The channels through which improved seeds influence agricultural intensification are technological, economic and institutional, and are specific to each household (De La Paix Bayiha et al., 2020; Andrianarison et al., 2021). For example, Meughoyi (2018) demonstrated in his research that the adoption of improved maize seeds by Cameroonian farmers was associated with increased productivity. The potential productivity of farmers who adopt improved maize varieties is 1.42 times higher than that of farmers who adopt conventional varieties. Similarly, the productivity gap between adopters and non-adopters is estimated at 0.351 kg/ha. Meughoyi (2018) therefore concludes that adopting improved varieties leads to the intensification of maize production in Cameroon. A study by Takam-Fongang et al. (2019) also revealed that 47.65% of farmers in central Cameroon had adopted improved maize varieties, achieving yields of 1,938.04 kg/ha compared to 1,263.17 kg/ha for non-adopters. However, despite this adoption, actual yields remain below potential, with 68.82% of farmers reusing their seeds.

However, while the impact of improved maize varieties on agricultural yields has been studied, the role of improved seeds in the sustainability of agricultural intensification in Cameroon has not yet been examined in a large-scale study. This is precisely the gap that the present study aims to fill.

MATERIALS AND METHODS

Nature and source of the data

The data used in this study were obtained from secondary sources and taken from the most recent Comprehensive Cameroon Food Security and Vulnerability Assessment (CFSVA). This national study, conducted in 2017 by the World Food Programme in partnership with the Cameroonian government, assessed food insecurity and household vulnerability in Cameroon. The study aimed to assess households' access to production resources, particularly improved seeds, identify those most vulnerable to climate shocks, and provide data to inform development policies (WFP, 2017). Based on these objectives, a random sample of 4,101 rural households was selected, taking into account the adoption of improved maize seeds and increases in maize yields.

Measurements of key variables in the analysis

In this study, the adoption of improved maize seeds and the intensification of maize production are the two main explanatory variables. A household is classified as an "adopter" if it used improved maize seeds at the time of the survey and as being in the "intensification" phase if it increased its maize production during the survey year (Shiferaw et al., 2014).

In non-experimental studies, assessing the impact of improved seeds on agricultural production usually involves addressing selection bias among households, given that adoption or non-adoption is not random. This method provides an unbiased and consistent estimate of the impact of adoption. Adopters and non-adopters of improved seeds with similar characteristics are therefore assigned a propensity score (PSM), which reduces bias associated with observed variables (Rosenbaum & Rubin, 1983).

For the output variables, this study examines the Technical Efficiency (TE), Allocative Efficiency (AE) and Economic Efficiency (EE) of households involved in maize production. TE, AE and EE scores range from 0 to 1: a score of 1 indicates maximum efficiency and the optimal use of resources, while a score of 0 represents a complete lack of efficiency in production. Therefore, intermediate values suggest a combination of efficiency and inefficiency, as well as the potential for increased agricultural production. Higher TE, AE and EE values suggest intensified production.

Framework for estimating the empirical model

The econometric estimation framework used in this study employed a specific Stochastic Frontier Analysis (SFA) to calculate the TE, AE and EE indices. The results of this analysis are presented in the section on the empirical strategy.

Technical inefficiency was estimated using a stochastic frontier and then incorporated into a regression model to identify the influencing factors. However, missing variables affected this procedure, contradicting the assumption regarding the distribution of inefficiency effects. To address this issue, this study applied Maximum Likelihood Estimation (MLE), as recommended by Kumbhakar and Lovell (2003), alongside Least Squares Estimation (LSE) to estimate the stochastic frontier and inefficiency model simultaneously.

The SFA, developed by Aigner et al. (1977), is a parametric method used to assess efficacy based on a specific mathematical formula.

$$Y_i = f(x_i, \beta) \exp(v_i) \exp(-u_i) \quad (1)$$

where y_i is the output value of the i -th household, x_i is a vector of inputs, β is a vector of parameters to be estimated, and $v_i \sim N(0, \sigma_v^2)$ and $u_i \sim N + \left[f(u, \alpha), \varphi_u^2 \right]$ are the random error and inefficiency terms, respectively.

Battese and Coelli (1995) describe the estimation of the components of technical efficiency based on Equation 1 as follows:

$$u_i = f(u_i, \alpha) \quad (2)$$

A combination of statistical tools was used for the analysis, including descriptive statistics, percentages and econometric models. A probit regression analysis was performed to identify the factors influencing the intensification of maize cultivation in rural Cameroon. The analysis focused on production and cost functions in order to evaluate the efficiency of this agricultural intensification.

Mathematically,

$$l_n(1/1 - p) = bo + b_1X_1 + b_2X_2 + b_3X_3 \dots + b_nX_n \quad (3)$$

Where X_i is the combined effect of X explanatory variables that encourage or discourage households' decision from increasing their production.

Similarly,

$l_n(1/1 - p)$ = the logarithm of the probability of farming households deciding to intensify maize production by adopting improved seeds.

$X_1 \dots X_i$ are the factors that encourage or hinder rural households from intensifying their production. These factors are defined as follows: access to information, use of labour, use of improved seeds, proximity to a market, total land area, expenditure on food, non-food expenditure, expenditure on agricultural inputs, and the household's financial situation (wealth).

The maize production frontier function is estimated using a linear model.

$$l_n Y_i = \beta_0 + \beta_1 l_n X_{1i} + \beta_2 l_n X_{2i} + \beta_3 l_n X_{3i} + v_i - u_i \quad (4)$$

Where,

Y_i = production quantity per hectare in kg for the i -th household; X_{1i} = seeds in kg from the i -th household; X_{2i} = labour in man-days for the i -th household; X_{3i} = inputs (fertilisers and pesticides) in kg for the i -th household; β = a vector of unknown parameters to be estimated. v_i is the random variable (stochastic error term) which is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$; u_i is the non-negative estimate of the farm's technical inefficiency.

Similarly, the selected marginal cost function is:

$$l_n C_i = \beta_0 + \beta_1 l_n Y_i + \beta_2 l_n X_{1i} + \beta_3 l_n X_{2i} + \beta_4 l_n X_{3i} + v_i + u_i \quad (5)$$

Where,

C_i = total household expenditure on agricultural production Y_i = value of production per kg for the i -th household, X_{1i} = cost of seeds for the i -th household, X_{2i} = wages for labour provided by the i -th household, X_{3i} = input costs for the i -th household, β_0 = constant; $\beta_1 - \beta_4$ = cost function parameters; l_n = natural logarithm.

The term "error", which consists of two parts ($\varepsilon_i = v_i + u_i$), is defined as follows: v_i = random error caused by statistical noise,

weather conditions, illness, etc., which are beyond the control of households; u_i = risk (economic inefficiency) arising from household characteristics.

The framework for assessing technical, economic and allocative efficiency is therefore as follows:

$$a) TE_i = \frac{y_i}{\hat{y}_i} = \frac{Y_i}{f(x_i, \beta) \exp(v_i)} = \exp(-u_i) \quad (6)$$

$$b) EE_i = \frac{C_i}{\hat{C}_i} = \frac{C_i}{f(x_i, \beta) \exp(v_i)} = \exp(-u_i) \quad (7)$$

$$c) AE = EE/TE \quad (8)$$

Where,

Y_i is the observed output subject to inefficiency; y_i corresponds to the frontier output subject to inefficiency; X_i are the independent variables, u_i = error term. Total production cost (C_i) is relative to the actual total production cost C_i^* .

RESULTS AND DISCUSSION

Summary of descriptive statistics

Of the 4,101 households surveyed, 60.35% (2,475 households) grow maize intensively, while 39.65% (1,626 households) do not. Of those that do, 30.1% (745 households) use improved seeds, while 69.9% (1,730 households) do not. Table 1 provides the definitions and summary statistics for the variables used in the analysis.

Table 1. Descriptive statistics for the variables used in the study

Variable	Description	Mean	Std dev.
Age (age group 1)	1 = ≤30 years old ; 0 = otherwise	0.106	0.308
Gender (male)	1 = yes ; 0 = otherwise	0.837	0.37
Access to information	1 = yes ; 0 = otherwise	0.626	0.484
Cooperative	1 = member ; 0 = otherwise	0.037	0.189
Production	Average maize yield/ household (kg)	483.659	1006.064
Quantity of seeds	Quantity of seeds used/ household (kg)	27.791	57.13
Labour use	1 = use of external labour; 0 = otherwise	0.187	0.39
Quantity of inputs	Quantity of fertiliser & pesticides used/ household (kg)	226.248	441.064
Level of education (Higher)	1 = Higher education qualification; 0 = otherwise	0.019	0.135
Fishing and livestock	1 = yes ; 0 = otherwise	0.496	0.5
Household size (average size)	1 = ≤5 people; 0 = otherwise	0.209	0.407
Area 1	1 = Farming a plot of land ≤ 1ha ; 0 = otherwise	0.309	0.462
Area 2	1 = Farming a plot of land 1ha ≤ 2ha ; 0 = otherwise	0.358	0.48
Total areas	Total operational area/ household (ha)	1.897	1.494
Distance from the market	1 = Close to a market; 0 = otherwise	0.197	0.398
Expenditure on inputs	Household expenditure on inputs and pesticides (FCFA)	16675.198	58408.959

Variable	Description	Mean	Std dev.
Cost of seeds	Household expenditure on seeds (FCFA)	2568.752	9640.731
Labour expenses	Household's daily labour in exchange for food (%)	12.876	11.797
Consumption expenditure	Total household expenditure on consumption (FCFA)	131,093.05	304,103.78
Expenditure on food	Food expenditure/ household's own production	39.802	17.115
Non-food expenditure	Total consumption expenditure/ household, spent on non-food items	0.007	0.039
Household wealth	1 = "non-poor"; 0 = otherwise	0.202	0.301
Total agricultural expenditure	Expenditure on agricultural production (FCFA)	25,736.689	96,081.75
Use of improved seeds	1 = yes; 0 = otherwise	0.301	0.459

Source : Author's calculations

The majority of households that grow maize – 83.7% – are headed by men over the age of 30. Only 19.1% of these household heads have a university education, and around 21% of these households are medium-sized (six to eight people) and own around two hectares of arable land. However, the majority often farm on less than one hectare (20.2%). Some of these non-poor households (30.1%) are located far from markets and have limited access to credit (19.4%), but enjoy satisfactory access to information (62.6%). The average cost of maize seeds is 2,568.75 CFA francs (4.56 US dollars), while the cost of other inputs amounts to 16,675.20 CFA francs (29.62 US dollars). Furthermore, only 3% of household heads belong to a cooperative, and households employ barely 1% of external labour. The average production per household is 483.65 kg, with 27.79 kg of seeds and 226.25 kg of other inputs used. Around 49.6% of households diversify their activities by engaging in fishing and livestock farming. Finally, analysis of agricultural expenditure (an average of 25,736.69 CFA francs, equivalent to 45.71 US dollars) and household consumption expenditure (an average of 131,093.05 CFA francs, equivalent to 232.85 US dollars) illustrates the intensification of maize production.

Factors influencing rural households in Cameroon to adopt improved maize seeds

The validated regression model (pseudo-R-squared= 0.037) includes 12 independent and 1 dependent variable relating to the adoption of improved seeds. Eight of these variables positively influence the adoption of these seeds.

Table 2. Characteristics of the adoption of improved maize seeds in rural areas of Cameroon

Dependent variable: Use of improved seeds	Probit coefficients	Marginal effects
Age (age group 1)	0.138** (0.0681)	0.0461** (0.0234)
Gender (male)	0.227*** (0.0645)	0.0693*** (0.0185)
Access to credit	0.108* (0.0590)	0.0354* (0.0198)
Access to information	0.273*** (0.0447)	0.0866*** (0.0139)
Cooperative	0.216* (0.124)	0.0739* (0.0445)
Level of education (Higher)	0.397***	0.142**

Dependent variable: Use of improved seeds	Probit coefficients	Marginal effects
	(0.153)	(0.0587)
Fishing and livestock	0.130*** (0.0435)	0.0418*** (0.0140)
Household size (average size)	-0.163*** (0.0541)	-0.0508*** (0.0163)
Area 1	-0.306*** (0.0553)	-0.0950*** (0.0165)
Area 2	-0.193*** (0.0519)	-0.0610*** (0.0161)
Distance from the market	-0.158*** (0.0531)	-0.0494*** (0.0161)
Consumption expenditure	1.25e-07** (6.28e-08)	4.03e-08** (2.03e-08)
Constant	-0.892*** (0.0812)	
Observations	4101	4101
Mean dependent variable	0.265	
Pseudo r-squared	0.037	
Chi-square	174.514	

Note: Error terms in brackets *** p<0.01, ** p<0.05, * p<0.1

Source: Author's calculations

An analysis of the estimates in Table 2 shows that the variables relating to access to credit and cooperative membership are significant at the 1% level, while age, level of education, and consumer expenditure are significant at the 5% level. The main factor determining the adoption of improved seeds is level of university education, accounting for 14.2%. Similarly, gender, access to information, and fishing and livestock farming practices are significant factors, accounting for 10%. Conversely, household size, cultivated area and distance from the market negatively affect the adoption of these seeds. For instance, households located further from markets are less likely to adopt improved seeds, as those in closer proximity benefit from the free flow of information. This enables them to increase their incomes through selling their produce and engaging in non-agricultural activities (Tadesse & Bahigwa, 2015). However, proximity to markets for inputs and raw materials reduces uncertainty and offers greater flexibility in the face of production fluctuations, enabling rural households to access improved seeds (Teklewold et al., 2013; Khonje et al., 2018).

These findings are consistent with those of Nkurunziza et al. (2021) and Ngango et al. (2022), who found that the adoption of sustainable agricultural intensification practices is influenced by factors such as education, farm size, livestock ownership, group membership and agricultural extension services, as well as environmental conditions such as soil type and climate. Economic factors such as crop yields, household income and expenditure also influence sustainable agricultural intensification. Furthermore, the findings partially corroborate the work of Ntsama and Kamgnia (2008) and Mabah et al. (2013), which indicates that rural households in Cameroon adopt improved maize varieties depending on factors such as location, area under cultivation, relations with extension services, level of education, household size, and membership of agricultural organisations. Medium-sized rural households, which often lack labour for agricultural work, tend to opt for improved seeds as a means of compensating for this shortfall (Feder et al., 1985; Mwangi & Kariuki, 2015). The sex ratio and level of education also appear to significantly influence this process: men have better access to food production resources (Mwangi & Kariuki, 2015), and a high level of education

enables them to make better decisions based on available information, deriving the greatest benefit from adopting these seeds (Mwangi & Kariuki, 2015). Finally, adopting improved seeds becomes more challenging with age as people tend to adhere to established practices as they grow older (Feder et al., 1985; Mwangi & Kariuki, 2015).

Factors influencing sustainable intensification of maize production in rural Cameroon

When used appropriately, the binary Probit model explained 60.82% of the observed variation in household behaviour regarding the intensification of maize production in rural areas of Cameroon (see Table 3).

Table 3. Characteristics of sustainable maize production intensification in rural areas of Cameroon

Dependant variable: Production	Probit coefficients	Marginal effects
Access to information	0.158*** (0.0439)	0.0610*** (0.0169)
Labour use	0.143** (0.0589)	0.0541** (0.0219)
Use of improved seeds	0.218*** (0.0474)	0.0823*** (0.0175)
Distance from the market	-0.167*** (0.0485)	-0.0647*** (0.0190)
Total area	0.0271** (0.0138)	0.0104** (0.00530)
Expenditure on food	-0.00425*** (0.00116)	-0.00163*** (0.000446)
Non-food expenditure	-1.527*** (0.449)	-0.587*** (0.172)
Expenditure on inputs	2.425*** (0.434)	0.931*** (0.166)
Household wealth	-0.247*** (0.0447)	-0.0955*** (0.0173)
Constant	0.319*** (0.0674)	
Observations	4094	4094
Mean dependent variable	0.604	
Pseudo r-squared	0.039	
Chi-square	216.258	

Note: Error terms in brackets *** p<0.01, ** p<0.05, * p<0.1

Source: Author's calculations

Thus, access to information, labour utilisation, adoption of improved seeds, total cultivated area, and input expenditure all positively impact the intensification of maize cultivation. For instance, investing in fertilisers and pesticides alongside the use of improved seeds increases the likelihood of intensifying maize production by 93.1%.

Estimates of propensity scores

The impact of improved seeds on the sustainable intensification of maize production by rural households is assessed by taking all observable covariates influencing their use into account.

Table 4. Propensity scores for adopting improved maize to achieve sustainable intensification in rural areas of Cameroon

Variable	Coefficient	Std. error	Estimation (z)
Age (age group 1)	0.135	0.068	1.980**
Gender (male)	0.232	0.064	3.600***
Access to credit	0.111	0.059	1.880*
Access to information	0.281	0.045	6.300***
Cooperative	0.222	0.123	1.800*

Variable	Coefficient	Std. error	Estimation (z)
Fishing and livestock	0.129	0.043	2.970***
Household size (average)	-0.159	0.054	-2.940***
Area 1	-0.304	0.055	-5.500***
Area 2	-0.192	0.052	-3.710***
Distance from the market	-0.159	0.053	-3.000***
Consumption expenditure	0.000	0.000	2.070**
Constant	-0.895	0.081	-11.030***
Log likelihood	-2288.648		
Observations	4101		
Model's X ²	167.80		
Prob > chi2	0.0000		
Pseudo r-squared	0.0354		

Note: Error terms in brackets *** p<0.01, ** p<0.05, * p<0.1

Source: Author's calculations

Table 4 analyses various factors influencing the adoption of improved maize seeds for sustainable intensification in rural areas of Cameroon, such as the age and gender of the head of household, access to credit and information, membership of a cooperative, and the practice of fishing and livestock farming. The table also examines household size, cultivated land area, proximity to a market, and household expenditure. These factors influence the adoption of improved maize seeds for sustainable intensification in rural areas of Cameroon. Clearly, rural households that adopt improved maize seeds are able to intensify maize cultivation by gaining better access to information, making increased use of external labour, expanding their arable land and investing in fertilisers and pesticides. Thus, with agricultural inputs held constant, households using improved maize seeds achieve higher yields than those that do not, suggesting that the adoption of improved seeds is intended to increase production. However, household size, the area of cultivated land, and proximity to a market are linked to a threshold effect that limits this impact.

The impact of adopting improved seeds on the intensification of maize production in rural Cameroon

The average impact of adopting improved seeds (ATT) is estimated using the nearest-neighbour matching method. The standard errors of these estimates are then calculated using bootstrapping with 100 replications.

Table 5. ATT of improved seeds on the intensification of maize production in rural areas of Cameroon

Group	Treatment	Comparison	Diff.	Std. error	t-stat
Unmatched	344.134	273.030	71.104	28.863	2.460
ATT	344.450	291.675	52.775	45.196	1.170
Bootstrap	100	100	100	100	100

Source: Author's calculations

On average, Table 5 shows that rural households that adopt improved maize seeds increase their yield by approximately 344.45 kg/ha, compared to 291.675 kg/ha for those that do not use them. Adopting improved maize seeds leads to higher yields: on average, households that adopt them produce 45.19 kg/ha more than those that do not. This positive ATT suggests that maize cultivation is being intensified through the use of improved seeds. This result is also observed in the unmatched group, albeit to a lesser extent. In this context, adopting improved seeds is essential for reducing labour costs and increasing profitability.

Following matching, no significant differences were observed in the means of the explanatory variables. Households that adopt improved

maize seeds and those that do not are comparable in terms of observable variables, making the comparison statistically valid.

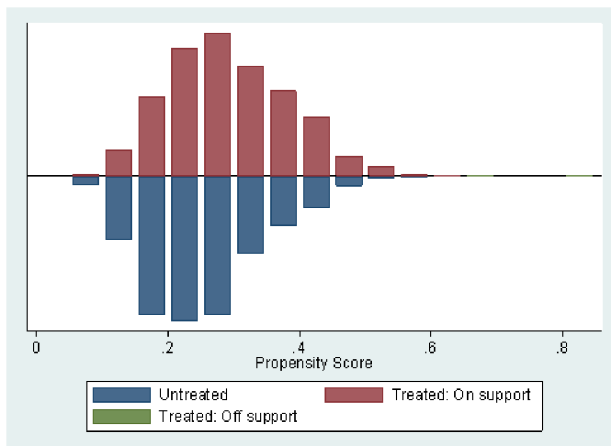


Figure 2. PSM distribution of improved maize seeds adoption in rural areas of Cameroon.

Similarly, when considered in conjunction with the distribution of propensity scores and common controls, the analysis shows that the distribution of propensity scores amongst maize-farming households is virtually zero, with an average overlap in probabilities between households that have adopted improved seeds and those that have not.

Estimation of the SFA production and cost functions for maize intensification

The results show that, at a 1% significance level, seed quantity, labour input and the quantity of inputs are significant independent variables in the stochastic production function.

Table 6. Maximum likelihood estimates of the parameters of the SFA production function

Boundary production function (normal/semi-normal)			
Variable	Production	ϕ_v^2	ϕ_u^2
Quantity of seeds	0.838*** (1.28e-05)		
Labour use	-0.447*** (7.16e-06)		
Quantity of inputs	-0.484*** (1.26e-05)		
Constant	5.197*** (5.16e-05)		
Observations	4101	4101	4101
Mean dependent variable	4.810		
Log likelihood	-8.7913455		
Prob > chi2	0.000		
SD dependent var	0.744		

Note: Error terms in brackets *** p<0.01, ** p<0.05, * p<0.1

Source: Author's calculations

According to Table 6, only the quantity of seeds exhibits a positive relationship with production, meaning that an increase in this variable results in an increase in production. In contrast, the coefficients for the labour-related variables and the quantity of inputs in the production function suggest that a one-unit change in these variables results in a 44.7% and 48.4% reduction in production, respectively. This can be explained by the law of diminishing returns, which states that increasing labour, fertilisers and pesticides boosts production up to a certain point, after which the effect becomes negative. Finally, the analysis shows that 74.4% of the gap between actual and potential

maize production is due to the technical inefficiency of crop intensification.

At the same time, analysis of the cost function (SFA) shows that the cost of factors such as seeds, labour, pesticides and fertilisers directly impacts the cost of intensifying maize production.

Table 7. Maximum likelihood estimates of the parameters of the stochastic frontier cost function

Boundary production function (normal/semi-normal)			
Variable	Total agricultural expenditure	ϕ_v^2	ϕ_u^2
Production	0.0538* (0.0327)		
Cost of seeds	38.80 (29.44)		
Labour expenses	0.0208 (0.0485)		
Expenditures on inputs	-38.67 (29.44)		
Constant	78.12 (52.79)	-0.691*** (0.0919)	-10.61 (176.8)
Observations	4094	4094	4094
Log likelihood	-254.443004		
Prob > chi2	0.000		
SD dependent var	0.744		

Note: Error terms in brackets *** p<0.01, ** p<0.05, * p<0.1

Source: Author's calculations

The constant term of -0.691 is significant at the 1% level because expenditure on fixed production factors, such as land and agricultural machinery, remains constant regardless of output. The positive coefficients for intensified production (0.05), the cost of seeds (38.8) and labour expenditure (0.02) indicate that an increase in the use of these factors will lead to a rise in total agricultural expenditure. However, since the coefficient for inputs is negative (-38.67), an increase in this variable whilst holding all other factors constant may reduce the household's total agricultural expenditure.

Thus, although adopting improved seeds can increase maize production, this remains inversely proportional to labour and resources. Consequently, production efficiency depends on a combination of rural households' internal resources and external inputs, such as seeds, fertiliser, and pesticides. Similarly, the intensification of maize production is negatively correlated with households' financial capacity, suggesting that better finances lead to more efficient production. An increase in the cost of seeds leads to a rise in the total cost of production. In contrast, a change in the cost of fertilisers and pesticides could result in a significant reduction, as households may choose not to use them when growing maize. Therefore, it is essential to ensure the timely availability of these additional resources and the labour required to utilise them (Tiffen & Mortimore, 1994).

However, the efficiency terms follow a truncated normal distribution because ϕ_u^2 is not statistically different from zero. This reflects the presence of inefficiency in maize production in rural areas of Cameroon. This inefficiency is primarily caused by factors outside the control of households, as the estimates of ϕ_v^2 and ϕ_u^2 are negative. This is likely due to environmental factors such as drought and flooding. The influence of random effects contributes to economic inefficiency, while increased external labour costs raise households' total agricultural expenditure.

Estimating the technical, allocative and economic efficiencies of intensifying maize cultivation among rural households in Cameroon

Table 8 shows that households in rural areas achieved technical, allocative, and economic efficiency rates of 52%, 81.5%, and 70.9%, respectively. This suggests that adopting improved maize seeds alongside other inputs is an effective production strategy. Conversely, the least efficient households require 31.2% more inputs to improve their efficiency, while the least economically efficient households need to make savings of 37.2% to become more efficient.

Table 8. Efficiencies of maize intensification in rural areas of Cameroon

Variable	Observations	Mean	t-stat	Min	Max
TE	4101	0.520	0.312	0.159	0.996
AE	4094	0.815	0.372	0.726	0.916
EE	4094	0.709	0.416	0.415	0.988

Source: Author's calculations

Although there is potential to improve the efficiency of rural households in the context of sustainable maize production intensification, the difference in average efficiency between households can only really be explained by the adoption of improved seeds, based on the average values for TE, AE and EE. Households that adopt improved maize seeds produce a higher yield with the same inputs as those that do not, and most of these households are efficient, achieving an average yield of 344.45 kg/ha. However, this yield is lower than the 530.35 kg/ha and 578.15 kg/ha reported by Takam Fongang et al. (2018). This suggests that households using improved maize seeds are more efficient and waste less in production than those that do not adopt them.

CONCLUSIONS

This study examined the theoretical, conceptual and empirical dimensions of the relationship between the adoption of improved maize seeds and sustainable agricultural intensification in rural areas of Cameroon. Overall, the analysis indicates that it is a complex and evolving relationship that necessitates various agricultural approaches tailored to existing systems to meet the needs of rural households. The main objective is to improve the efficiency with which other agricultural resources are used to enhance the overall efficiency of agricultural production. Therefore, the sustainability of agricultural intensification presents a technological challenge, and the adoption of improved seeds is considered an effective strategy for increasing agricultural production in a cost-effective and socially sustainable manner while mitigating the depletion of production resources. These seeds reduce pressure on production resources and improve rural household livelihoods, delivering economic, social and environmental benefits. They also improve the efficiency of agricultural production in rural areas by increasing yields and reducing input wastage. However, intensification through the use of fertilisers, pesticides and labour can hinder the adoption of improved seeds.

In Cameroon, rural households that choose to produce maize efficiently are influenced by the adoption of improved seeds, which promote sustainable, intensive production. However, the uptake of these seeds remains low due to inefficient supply chains, which hinders sustainable maize production. This situation is exacerbated by the degradation of natural resources and the pressures on rural households arising from their socio-demographic, economic, and institutional characteristics. These characteristics also encompass technological factors, such as the use of variable inputs and labour,

that are comparable to those involved in the sustainable intensification of agricultural production.

The findings of this study have significant implications for public policy and the economy. Consequently, any strategy aimed at promoting sustainable agricultural intensification for rural households in Cameroon should emphasise the systematic adoption of improved seeds, while also incorporating diversified farming systems, lower input prices, a favourable socio-economic environment, and support services for farmers. In particular, the supply of improved seeds should be increased, and markets and producer organisations should be supported to establish sustainable seed systems. These measures will promote efficient production, increase yields, and reduce losses among rural households.

However, while this study presents significant findings, it has methodological shortcomings, most notably a lack of data and indicators relating to environmental sustainability. The study was based on the 2017 CVFSA database, which focuses solely on maize yields associated with the use of improved seeds. Key ecological indicators, such as changes in land use and biodiversity, which are important for sustainable intensification, were omitted. Furthermore, the study is based on data from a single growing season, whereas environmental sustainability requires long-term monitoring. A more comprehensive analysis would enable the impact of improved maize seeds on natural resources to be assessed, while ensuring that increased agricultural yields do not harm ecosystems in rural Cameroon.

AUTHOR CONTRIBUTIONS

Conceptualisation: P.M. and P.N.; methodology: P.M.; data management: P.M.; formal analysis: P.M.; research: P.M. and P.N.; drafting of the first version: P.M.; supervision: P.N. All authors have read and approved the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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DATA AVAILABILITY

The 2017 Cameroon Food Survey and Vulnerability Analysis (CFSVA) is available and has been provided to the journal.

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